

Muon (g-2) in models with a very light gravitino

ELENA PERAZZI

*Istituto Nazionale di Fisica Nucleare, Sezione di Padova,
Dipartimento di Fisica ‘G. Galilei’, Università di Padova,
Via Marzolo n.8, I-35131 Padua, Italy*

We present the results of a general analysis of the contributions of the supersymmetry-breaking sector to the muon anomalous magnetic moment in models with a superlight gravitino. We find constraints on the model parameters that are comparable and complementary to the ones coming from collider searches, and will become more stringent after the Brookhaven E821 experiment.

The measurement of the anomalous magnetic moment of the muon,

$$a_\mu^{ex} \equiv (g_\mu - 2)/2 = (116592350 \pm 730) \times 10^{-11}, \quad (1)$$

together with the theoretical prediction of the Standard Model,

$$a_\mu^{SM} = (116591596 \pm 67) \times 10^{-11}, \quad (2)$$

provides a very powerful constraint on extensions of the SM: from comparison between eqs. (1) and (2) we find, for possible contributions δa_μ from New Physics, the 95% confidence level bound: $-0.7 \times 10^{-8} < \delta a_\mu < 2.2 \times 10^{-8}$. Moreover, the E821 experiment at Brookhaven ¹ is expected to reduce further the experimental error by roughly a factor of 20.

The full one-loop contribution to a_μ in the Minimal Supersymmetric Standard Model (MSSM) is well known: the only case in which δa_μ can become relevant is when the masses of supersymmetric particles are close to their present lower bounds and $\tan \beta = v_2/v_1$ is very large.

We performed² a general analysis of the one-loop contributions to δa_μ in supersymmetric models with a light gravitino, where the effective low-energy theory contains, besides the MSSM states, also the gravitino and its superpartners. Most of the existing calculations of these effects were performed in the framework of supergravity (the most complete one is that of ref. ³); however, in the case of a light gravitino (the only phenomenologically relevant one for this type of study), we can work directly in the globally supersymmetric limit, keeping only the goldstino and its spin-0 superpartners (sgoldstinos) as the relevant degrees of freedom from the supersymmetry-breaking sector.

We constructed² the most general $N = 1$ globally supersymmetric model whose physical content consists of: $U(1)$ gauge boson and gaugino (A_μ, λ) , associated with the exact gauge symmetry of supersymmetric QED; left-handed muon and related smuon $(\mu, \tilde{\mu})$ (with charge -1); left-handed anti-muon and related smuon $(\mu^c, \tilde{\mu}^c)$ (with charge $+1$); finally, neutral goldstino and sgoldstino (ψ_z, z) .

The model is characterized by the following spectrum parameters: the muon mass m_μ ; two different squared masses m_1^2 and m_2^2 and a mixing angle θ (related to the smuon off-diagonal mass parameter $\delta m^2 \equiv (m_1^2 - m_2^2) \sin(2\theta)/2$) for the smuons; two different squared masses m_S^2 and m_P^2 for the sgoldstinos ($z \equiv (S + iP)/\sqrt{2}$); the photino mass M_λ .

In addition, we must consider the supersymmetry-breaking scale, \sqrt{F} , and two additional parameters, γ_f and γ_K . These are all the parameters relevant for the one-loop computation of δa_μ .

In the model described above, the different classes of one-loop Feynman diagrams that may contribute to a_μ (in addition to the well-known QED and SQED ones) are displayed in fig. 1. In ref.² we presented the results in their most general form; here we would like

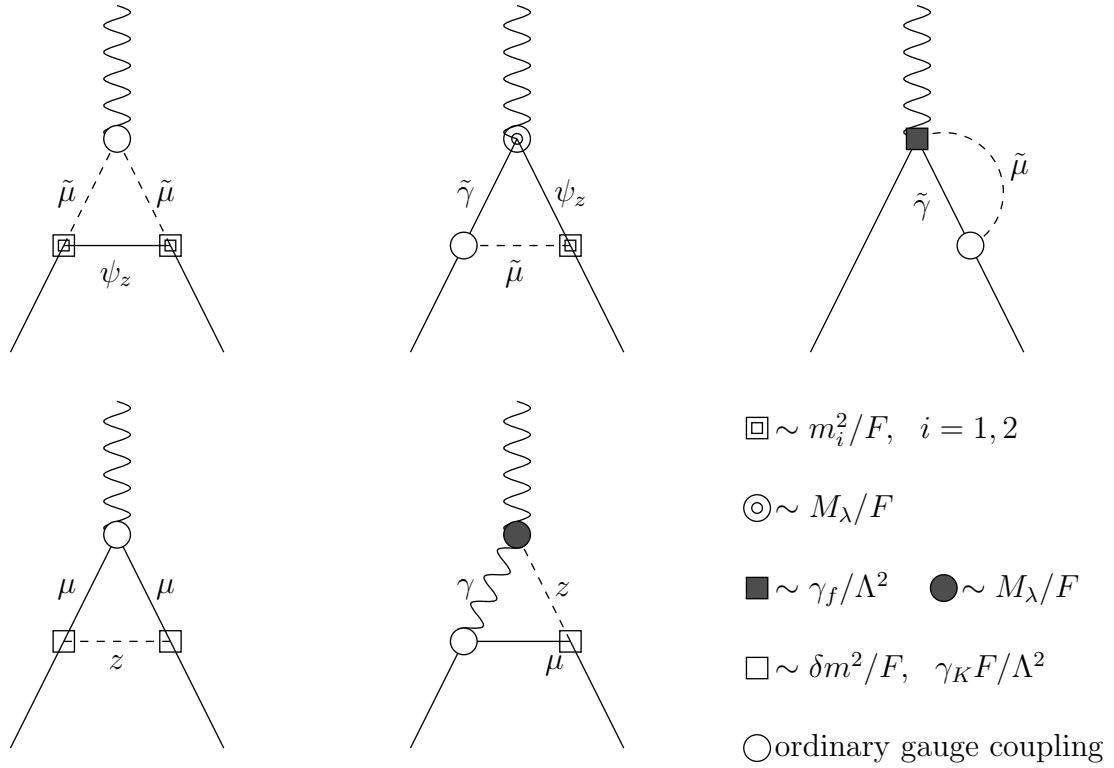


Figure 1: *The different classes of one-loop diagrams contributing to a_μ , together with the parameters controlling the different couplings*

to point out their main features and to comment on their possible interpretation. The first thing to say is that we found a logarithmically divergent contribution to a_μ

$$\delta a_\mu^{(DIV)} = (2\gamma_K - \gamma_f) \frac{m_\mu M_\lambda}{8\pi^2 \Lambda^2} \log \frac{\Lambda_{UV}^2}{\mu^2}, \quad (3)$$

where Λ_{UV} is a cutoff in momentum space, Λ is the suppression scale of non-renormalizable terms in the Lagrangian and μ is the renormalization scale. This result is in agreement with those obtained within the supergravity formalism³.

Since the existence of such a contribution limits somewhat the predictive power of our effective theory, we could look for a class of divergence-free models. We could just impose $\gamma_f = 2\gamma_K$, but it would be better to address the question in terms of symmetry arguments. Indeed, we presented² an R-symmetry which forbids the divergent one-loop contributions, but unfortunately it forbids also gaugino mass M_λ , thus making difficult the construction of a realistic model with the full Standard Model gauge group.

A milder requirement may be to ask for a symmetry that forces the divergent contribution, eq. (3), to be at least proportional to m_μ^2 . An obvious candidate is a chiral $U(1)_S$, under which the doublets $(\mu, \tilde{\mu})$ and $(\mu^c, \tilde{\mu}^c)$ have charge assignments whose sum is different from zero. Such a symmetry would be explicitly broken by a small parameter to allow for the muon mass term. As a consequence, γ_f and γ_K would be suppressed by the same small parameter (and, also, we would have $\delta m^2 \equiv m_\mu A$, with $A = \mathcal{O}(M_S)$, the order of typical supersymmetry-breaking masses).

In such a framework, reasonable choices of the ultraviolet cutoff would produce contributions to a_μ that are of the same order of magnitude as the finite ones. Still, we cannot use the latter to make precise predictions on a_μ (in the absence of a satisfactory microscopic theory) but only to derive some ‘naturalness’ constraints on the model parameters (if we disregard the possibility of miraculous - or at least not yet understood - cancellations).

To discuss the phenomenological impact of the finite contributions, it is useful to parameterize all of them in a uniform fashion

$$\delta a_\mu \equiv \frac{m_\mu^2 M_x^2}{16\pi^2 F^2}, \quad (4)$$

where the square mass parameter M_x^2 can be positive or negative. The above form separates the dependence of δa_μ on the spectrum (through M_x) from that on the supersymmetry-breaking scale \sqrt{F} .

The present experimental limit and the future sensitivity on M_x are then shown in fig. 2. This information should be combined with the explicit expression of M_x^2 in terms of the spectrum, which can be easily read off the results of ref.²

In particular, expressing M_x^2 as the sum of ‘goldstino’ and ‘sgoldstino’ contributions, $M_x^2 = M_{x(G)}^2 + M_{x(SG)}^2$, we have

$$M_{x(G)}^2 = m_1^2 \left[-\frac{1}{6} + \frac{M_\lambda^2}{m_1^2 - M_\lambda^2} \left(1 - \frac{M_\lambda^2}{m_1^2 - M_\lambda^2} \log \frac{m_1^2}{M_\lambda^2} \right) \right] + (1 \rightarrow 2), \quad (5)$$

and

$$M_{x(SG)}^2 = \begin{cases} 2AM_\lambda \log \frac{m_P^2}{m_S^2} + \mathcal{O}(A^2 m_\mu^2 / m_{S,P}^2) & (m_\mu \ll m_P, m_S) \\ 2AM_\lambda + A^2 & (m_S, m_P \ll m_\mu) \end{cases}. \quad (6)$$

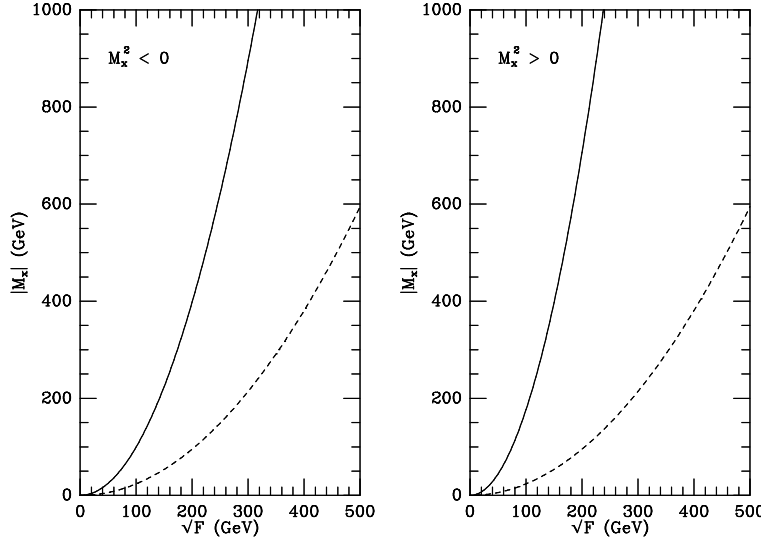


Figure 2: Contours of $\delta a_\mu \equiv m_\mu^2 M_x^2 / (16\pi^2 F^2)$ in the plane $(\sqrt{F}, |M_x|)$: the regions above the solid lines correspond to $\delta a_\mu < -70$ ($> +220$) $\times 10^{-10}$, and the dashed lines correspond to $\delta a_\mu = \mp 4 \times 10^{-10}$.

The size of the goldstino contribution to a_μ depends mainly on the smuon masses, and can be significant only for heavy smuons and a very low supersymmetry-breaking scale. The corresponding sign changes from positive to negative for increasing smuon-to-photino mass ratio.

The size of the sgoldstino contribution to a_μ depends on the photino mass, the sgoldstino masses and the parameter $A \equiv \delta m^2 / m_\mu$. The latter parameter plays a crucial role. Even if it would be in contrast with the above-quoted chiral symmetry, A could become much heavier than the typical superparticle mass M_S (e.g. it could be $\delta m^2 = \mathcal{O}(M_S^2)$), and the sgoldstino contribution could have an enhancement, in particular in the extreme case of superlight sgoldstinos $m_S, m_P \ll m_\mu$ (but the qualitative picture remains the same whenever at least one of the sgoldstino masses is $\lesssim m_\mu$).

In summary, with the present limits from accelerator searches (in particular the lower limit of roughly 200 GeV for \sqrt{F}), we can see that a_μ provides a non-negligible but mild constraint. Such a constraint will become much more stringent after the completion of the E821 experiment. If a discrepancy between the future E821 result and the SM prediction should emerge, models with a superlight gravitino might provide a viable explanation.

References

1. R.M. Carey et al., Phys. Rev. Lett. 82 (1999) 1632.
2. A. Brignole, E. Perazzi and F. Zwirner, preprint hep-ph/9904367.
3. F. del Aguila, Phys. Lett. B160 (1985) 87.